A MAC Layer Abstraction for Heterogeneous Carrier Grade Mesh Networks

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Abstract: Providing carrier grade services to a large number of mobile users is becoming an important challenge for wireless network operators. One promising solution for offering cost-efficient alternatives compared to classical cellular approaches is the use of wireless mesh networks along with the use of heterogeneous radio technologies. In this paper we propose a MAC abstraction layer to lessen the management burden of heterogeneous radio technologies. This abstraction layer is intended to hide the complexity and specifics of different wireless interfaces, this way supporting the use of a single set of routing and capacity handling mechanisms.

Keywords: carrier grade, mesh networks, Media Access Control, abstraction layer

1. Introduction

The number of mobile devices has significantly increased over the past years due to their cost reduction and larger market demand. Additionally, the interest of the Internet users is continuously shifting towards high rate data services, high quality multimedia applications and on-line gaming. Providing access to these types of services for large amounts of mobile users at a satisfactory quality is a costly endeavour for current cellular based providers. It is foreseen that classical wireless architectures will not be able to accommodate the demand that will arise with the evolution of the future mobile Internet [1]. Therefore, there is an obvious need for alternative solutions that can offer lower cost wireless access. One of the most promising candidate to fulfill these requirements are the wireless mesh networks (WMNs) [2].

As compared to current cellular access technologies, which rely on an hidden but complex infrastructure, mesh networking can provide a cost effective and efficient alternative for realising backhaul networks. This is because the multi-hop wireless architecture of mesh networks enables them to cover large areas without requiring each base station to be directly connected to the core infrastructure. More specifically, a mesh network is mostly comprised of nodes which only have wireless connectivity to their neighbours, with only a fraction of them connected to the operator's wired backbone. Furthermore, mesh networks have self-organising and self-optimizing capabilities, which enables them to dynamically adapt to the changing nature of the wireless medium and ultimately result in reduced up-front costs (CapEx) and lower network maintenance costs (OpEx) for the operator. The sum of the mentioned features leads to providing high quality services for mobile users.

Current deployments of mesh networks like e.g. Roofnet [3] are typically based on a single radio technology, generally IEEE 802.11 [4], due to its low cost and use of unlicensed spectrum. Despite the benefits in terms of management, choosing a single technology prevents an efficient and cost-effective deployment, as the suitability of radio technology heavily depends on the particular scenario in terms of user density, physical distances, traffic characteristics, etc. However, supporting different radio technology interfaces may introduce a high management burden, severely reducing the benefits of a mesh network approach. In this paper we present an architecture that tackles this technical challenge by designing an abstraction layer to hide most of the complexity of the radio interface management. This architecture is being developed by the CARMEN (CARrier grade MESh Networks) project.

The remainder of this paper is organized as follows. Section 2. presents the CARMEN architecture and its key comprising elements. Section 3. describes in detail the proposed MAC abstraction layer, including a use case example. Finally, Section 4. summarises the paper and exposes the directions of the future work.

2. A Carrier Grade Mesh Architecture

The CARMEN architecture aims to specify a WMN solution for providing triple-play operator services while supporting ubiquitous end-user connectivity using a heterogeneous technology backbone. Different technologies provide different tradeoffs in terms of - capacity, range, robustness, cost, etc. It is therefore envisaged that an operator's network would naturally comprise mixtures of these complementary technologies. Currently, two of the most compelling technologies which are under consideration for multi-hop mesh/relay standardization efforts are WiFi and WiMAX. These technologies can be selectively combined to realise a variety of heterogeneous mesh backhaul solutions that suit different usage or deployment requirements.

The key CARMEN objectives are: guaranteeing carrier-grade services, making an efficient use of the radio resources, supporting mobility, broadcast and multicast services, self-configuration. The CARMEN mesh provides end-users with carrier-grade access to communication services. The user terminals (UTs) are expected to be conventional devices with 802.21 support for mobility, while the core network is an IP-based infrastructure. Figure 1 depicts a typical CARMEN network topology introducing all types of CARMEN nodes:

- CARMEN Mesh Points (CMP). A CARMEN mesh point is a node within the CARMEN mesh that is equipped with CARMEN capabilities. CMPs forward traffic to/from the UTs, being aware of the requirements of the QoS requirements. A CMP may have one or more radio interfaces of different technologies, including 802.11 [4], 802.16 [5] and DVB [6].

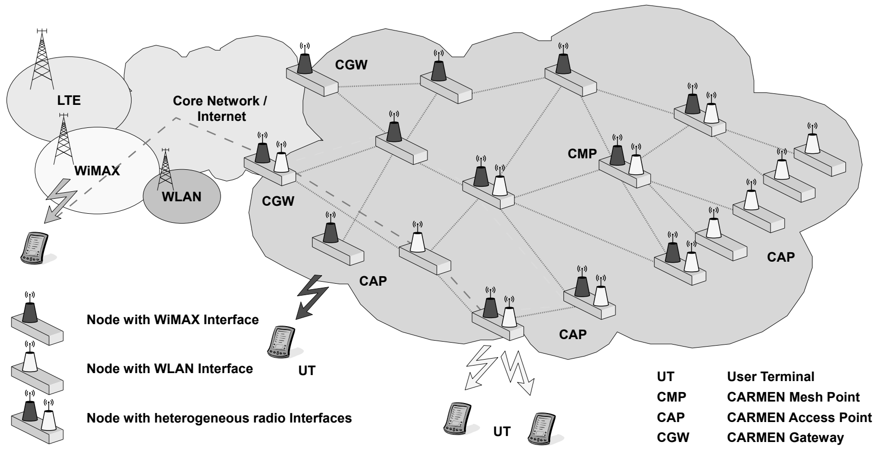

Figure 1: Network topology example

- CARMEN Access Points (CAP). A CAP is a CMP with the ability of providing UT access to the CARMEN mesh. The set of radio technologies employed on the access links may be different from those used within the CARMEN mesh.
- CARMEN Gateways (CGW). A CGW is a CARMEN mesh point that provides connectivity to the network provider's core network.

All the mesh network nodes may use heterogeneous wireless interfaces to communicate among them. To lessen the management complexity of such heterogeneity (e.g., for routing optimization), the CARMEN architecture relies on an abstraction layer to provide a common interface on top of the radio technologies. This MAC abstraction layer is detailed in what follows.

3. The CARMEN MAC Abstraction Layer

The extended functionality implemented by the proposed architecture in the mesh nodes, presented in Figure 2, is structured into two sub-layers: the MAC abstraction sub-layer and the CARMEN mesh functions sub-layer. The MAC abstraction sub-layer consists of the technology specific modules, used to handle the wireless devices, and a technology independent part, called Interface Management Function (IMF), which hides the complexity and specifics of each technology and provides a common set of primitives to the upper modules to implement the mesh functionality. This common interface is named Abstract Interface (AI) and incorporates part of the IEEE 802.21 [7] mobility features, but also provides additional means to support the mesh-specific requirements.

The CARMEN Mesh Functions sub-layer includes all mechanisms and algorithms needed for setting up a mesh topology and coordinating the mesh nodes to perform advanced func-

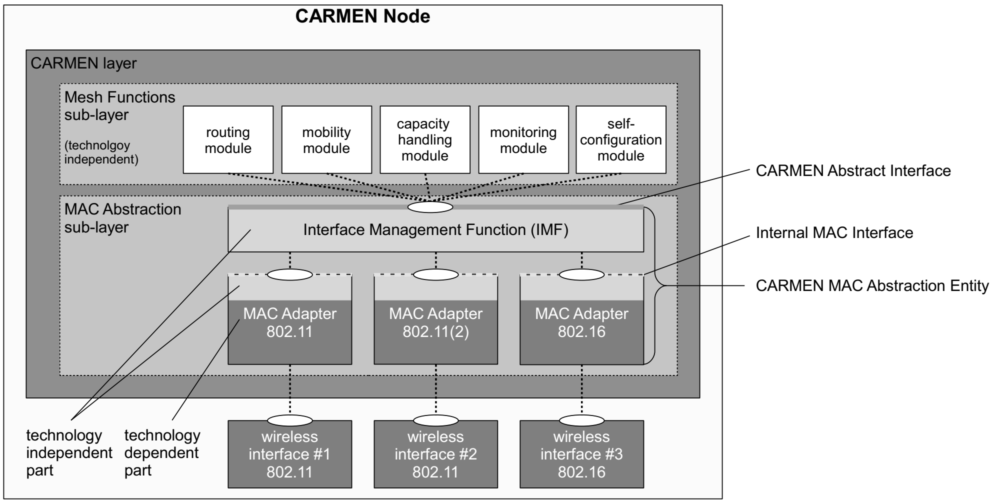

Figure 2: The sub-layers and building blocks of a CARMEN Mesh Point

tions such as routing (RtF), mobility management (MMF), capacity handling (CHF), self-configuration (SCF), and monitoring. These mesh functions are organized in modules which interwork with each other locally or remotely via interfaces.

Inside the CARMEN MAC Abstraction sub-layer, different wireless technologies are linked to the CARMEN AI by wireless technology dependent MAC Adapters. The MAC Adapters will include, with respect to the type of information they handle, a Technology Dependent Part (TDP) and a Technology Independent Part (TIP). The attachment of MAC Adapters to the Interface Manager will be realized by an internal interface, implementing most of the service primitives and using the same information representation as the CARMEN Abstract Interface.

From a prototype system point of view, the technology dependent part of the IMF have to be installed and instantiated according to the presence of wireless interfaces of the CARMEN node. The technology independent mesh functions are intended to be identical for all mesh nodes and may only differ slightly depending on the type of CARMEN node, i.e. whether it is a CMP, CAP, or CGW. This difference is rather behavioural in the sense that some of the mesh function modules may/may not be part of a node type or could act differently if the CARMEN node is connected to the backbone, it embeds AP functionality, or it is simply a mesh point.

The MAC abstraction layer will operate both at data and control plane level, providing means for media access and traffic forwarding considering QoS requirements, as well as support for mobility management and self-configuration of the radio interfaces. These features are detailed next.

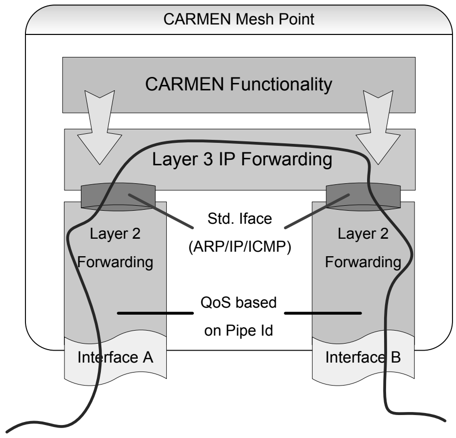

Figure 3: Forwarding model

3.1 — Data Plane

CARMEN aims to implement a forwarding solution with extended functionality on top of the existing implementations of the forwarding module in current operating systems, in order to avoid adding up complexity and rather focus on adding carrier-grade features. This implies that the standard interfaces and protocols between layer 3 and layer 2 will be left unmodified. Therefore, the IPv4/IPv6 addressing schemes, standard address resolution protocols ARP/NDP and control message protocols ICMP/ICMPv6 will be part of the protocol stack in every CARMEN node, as shown in Figure 3.

Traffic in the CARMEN backbone will be carried through pipes. A pipe consists of the aggregation of multiple user flows with similar end-to-end requirements and will be created at the ingress and egress nodes, along with a unique label (pipe ID). The Routing Function of CARMEN will ensure the forwarding tables are built such that traffic aggregates are forwarded to the next-hop based on the required QoS constraints, these being identified by the label. To implement the pipe ID two solutions are under study, namely MPLS labels or the IPv6 Flow Label field.

At intermediary mesh points, incoming packets will be decapsulated, passed through the look up process and delivered to the appropriate interface towards the next hop. The outgoing interfaces will encapsulate the packet in the specific data link technology. The MAC abstraction layer will enable performing resource reservations and priority based queuing to comply with the QoS requirements to which routing and capacity handling previously committed. It will map the pipe IDs to 1-hop QoS allocations and will schedule the packets according to their requirements.

3.2 — Control Plane

CARMEN architecture adopts the general IEEE 802.21 architecture [7] extending it to meet the requirements posed by the mesh topologies. The main difference between IEEE 802.21 and CARMEN abstraction layer lies within their scope, namely, while IEEE 802.21 focuses mainly on providing means to perform a seamless handover between heterogeneous technologies, CARMEN extends the 802.21 concept to globally manage a mesh network including heterogeneous wireless technologies.

The primitives implemented by the abstraction layer comprise event notifications, commands and information service. The function set of the CARMEN Abstract Interface extends the IEEE 802.21 Media Independent Handover Function (MIHF) beyond its original purpose to include QoS, self-configuration, routing and spectrum management support. This is achieved also by a close interaction with the monitoring aggregators (MoMa) that reside below the IMF and provide the means to have timely information about the wireless links, which is of significant importance when aiming to provide optimal usage of the mesh resources.

3.3 — Use Case Example

In order to better illustrate some of the functionality provided by the IMF through the CARMEN Abstract Interface, in this section we present an example of a use case, namely the node bootstrap. The goal of this process is to configure the wireless interfaces of all nodes with the parameters provided by the self-configuration function, to estimate the available resources (e.g. effective capacity of a shared link, foreseen delay bounds) and to provide initial QoS reservations support. At the end of the bootstrap phase, any node must be aware of its neighbours and be able of routing mesh traffic, as well as handling new pipe and flow requests. The process is summarized by the message sequence chart depicted in Figure 4.

A node begins its bootstrapping once it is turned on, by first detecting its capabilities. The Abstract Interface provides a set of primitives (AI_Get_Radios, $AI\_Radio\_Get\ \_Properties$ and $AI\_Radio\_Get\_Parameters$) that allow the self-configuration module to gather information about the parameters of each radio interface, e.g., technology used, physical address, sensitivity range, antenna properties. Once the information about the mesh topology is available through the use of measurement modules, self-configuration will run the radio optimisation algorithms to provide the best configuration found in terms of radio channel, power levels and modulation schemes. The AI also provides the necessary primitives for performing the radio parameters setup ($AI\_Radio\_Set\_Parameters$). Additionally, SCF provides an unique identifier for the shared medium, which will be used by the IMF to estimate the available resources and build node identifiers. Upon completing this phase, $Link\_Up$ events are issued to inform routing about the availability of the newly configured links. The indication primitives will provide the previously mentioned identifiers, the list of neighbours and the report on available capacity. After the capacity handling function is started it will attempt to perform the first QoS reservations in order to setup best-effort pipes for basic communication. This is supported by the AI through the $AI\_Link\_Allocate\_Resources$ primitives. The

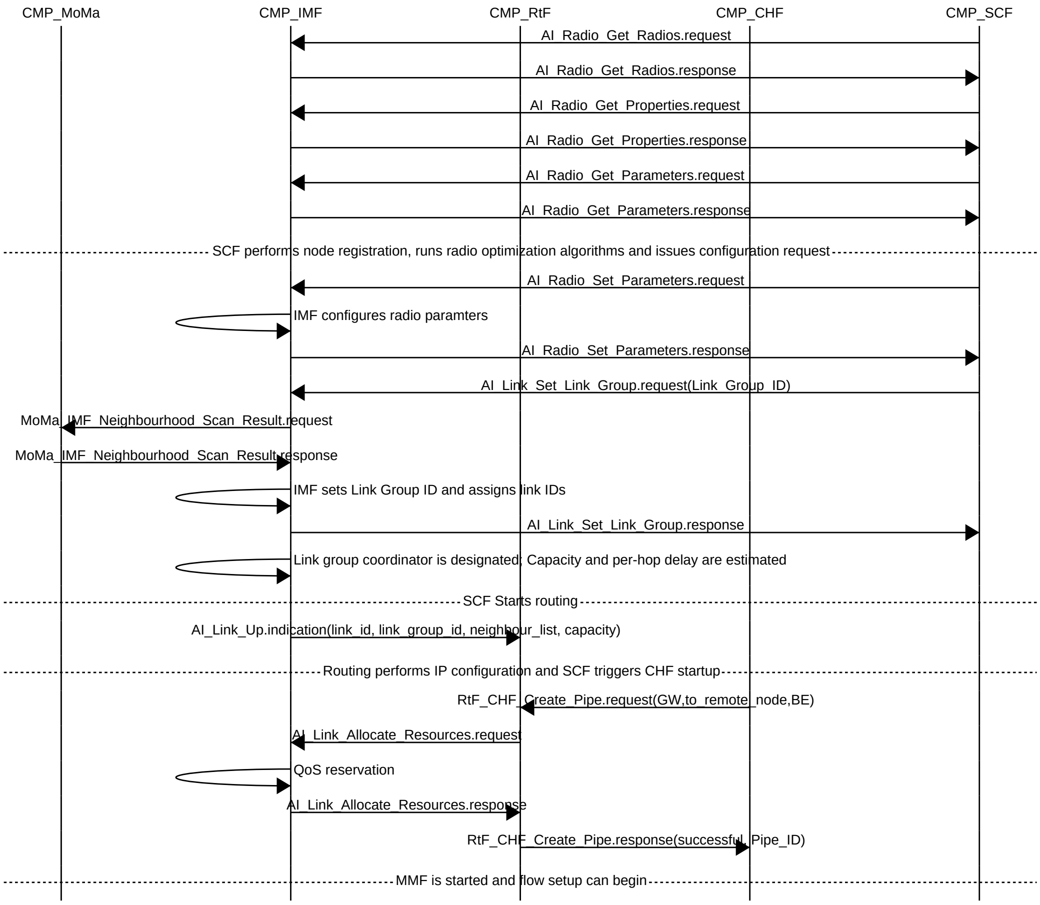

Figure 4: Message sequence chart for the bootstrap phase

bootstrap phase completes after the mobility management function is started and new flows can be admitted in the network.

4. Summary and Future Work

In this paper we have presented a novel architecture for WMNs to hide the complexity of heterogeneous radio interfaces by means of a MAC abstraction layer. This abstraction layer sits between the wireless devices and the upper layer modules (routing, mobility management, capacity handling and self-configuration), reducing the management complexity and enabling the provisioning of carrier grade services in an efficient and cost-effective manner. Preliminary cost analyses have shown that, depending on the scenario, wireless mesh networks may lead to noticeable cost reductions of up to around 50% compared to conventional non-mesh PMP solutions. This is assuming additional interferences resulting from mesh is minimal and additional cost incurred from wired backhaul subscription is insignificant compared to installation costs.

Despite the use of abstraction layers is not entirely new (e.g., the DAIDALOS project [8] used a similar approach in the context of future 4G networks), previous solutions were not specifically designed for the case of wireless mesh networks. In contrast, the CARMEN proposal specifically addresses the WMN requirements in order to achieve a reduced complexity and facilitate the use of self-management, recovery and reconfiguration mechanisms.

Future work will refine the design of this MAC abstraction layer and will focus on evaluating the performance of the proposed solution by means of practical simulations. This proposal will be assessed against classical cellular systems in terms of efficiency and cost, through evaluation under different scenarios implemented in testbeds that will incorporate various wireless technologies, such as IEEE 802.11, WiMAX and DVB.

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